

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-62,367

NASA TM X-62,367

ASSESS PROGRAM

**INTERACTIVE DATA MANAGEMENT SYSTEMS FOR
AIRBORNE RESEARCH**

Robert M. Munoz and John O. Reller, Jr.

**Ames Research Center
Moffett Field, California 94035**

**(NASA-TM-X-62367) ASSESS PROGRAM:
INTERACTIVE DATA MANAGEMENT SYSTEMS FOR
AIRBORNE RESEARCH (NASA) 46 p HC \$3.25
CSCL 29B**

N74-33676

**G3/08 49309
Unclas**

August 1974

ASSESS PROGRAM

INTERACTIVE DATA MANAGEMENT SYSTEMS FOR
AIRBORNE RESEARCH

Robert M. Munoz and John O. Reller, Jr.

Ames Research Center, Moffett Field, California 94035

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
INTRODUCTION	1
PART I - DESIGN PRINCIPLES AND APPLICATIONS TO FLIGHT SYSTEMS	3
BASIC CONSTRAINTS OF FLIGHT AND SPACE ENVIRONMENTS	4
AIRBORNE DATA ACQUISITION AND MANAGEMENT SYSTEM (ADAMS)	5
System Design Guidelines	5
System Functions	6
System Hardware	8
System Software	12
AIRBORNE DIGITAL DATA ACQUISITION SYSTEM (ADDAS)	19
Precursor Development	19
System Design Guidelines	20
System Functions	21
System Hardware	21
System Software	24
GROUND-BASED SIMULATOR	33
PART II - OPERATIONAL EXPERIENCE	35
DEDICATED FACILITY (C-141 ADAMS)	36
Integration and Checkout	36
Preflight Simulation	36
Utilization and Support Manpower	37
MULTIPURPOSE FACILITY (CV-990 ADDAS)	38
Integration and Checkout	38
Preflight Simulation	38
Utilization and Support Manpower	39
SYNTHESIS OF OPERATING PRINCIPLES AND INDICATED FUTURE DEVELOPMENTS	39
PART III - SHUTTLE SPACELAB APPLICATIONS	41
SHUTTLE SPACELAB APPLICATIONS	42
REFERENCES	43



INTERACTIVE DATA MANAGEMENT SYSTEMS

FOR AIRBORNE RESEARCH

By Robert M. Munoz and John O. Reller, Jr.

Ames Research Center

SUMMARY

Computer-centered systems for acquisition and processing of research data are evolving into new and more effective configurations that employ several small-scale, interactive computers with attendant peripheral units. Software concepts and utilization are likewise changing to keep pace, both to optimize the functional reliability of system hardware, and to permit rapid and reliable reprogramming for diverse uses of system resources.

Two such data systems have been developed by the Airborne Science Office (ASO) at Ames Research Center for use in airborne research. Both have "distributed intelligence" and are programmed for interactive support among computers and with human operators. The C-141 system (ADAMS) performs flight planning and telescope control functions in addition to its primary role of data acquisition; the CV-990 system (ADDAS) performs data management functions in support of many research experiments operating concurrently. Each system is arranged for maximum reliability in the first priority function, precision data acquisition.

The control and data management capabilities of these airborne systems will have their counterparts in Shuttle Spacelab installations, and will support research experiments in a similar manner. To the extent that these Spacelab systems can be made adaptable and interactive, they can enhance the performance of scientists in the orbital research environment, and provide the means for optimum response to new or changing research opportunities. To this end, the present report of ASO experience may aid planning for Spacelab data management systems.

INTRODUCTION

The meteoric rise of minicomputers has had a profound effect on the design of modern data systems in recent years. The history of scientific data acquisition started with relatively simple measuring instruments, with the only intelligence being that of the investigator. But now in an age of nuclear fusion and men walking on the moon, experiments are performed in vehicles that orbit the earth; the intelligence of the investigator is augmented by a multiplicity of computers, while primitive recording methods have given way to reels of digital magnetic recording tape and large-scale computing complexes. It is certainly not our intent to review the entire

evolution of the design of scientific data systems, but we will outline one aspect of this evolution as it relates to the data systems used in the research aircraft of the Airborne Science Office at Ames Research Center. One motive for doing this is to provide a basis for further development in the design of future intelligent data systems, especially those of the Shuttle Spacelab in the orbital environment.

The systems that we will describe here are far more than an aggregation of instruments in a vehicle. They consist of instruments, in part augmented by computers and recording devices, orchestrated by software to accommodate scientific and environmental changes, and controlled by several persons including systems operators and scientific investigators. The domain of the system encompasses both men and machines, software and hardware, not all of which is in the vehicle. The systems are adaptive and interactive. They permit changes from mission to mission and experiment to experiment, and within a single mission or experiment as well. This paper outlines the broader aspects of the total system, with an emphasis on components that perform their functions in flight.

We begin with a brief review of basic environmental and operational constraints that have influenced the design of both airborne and orbital systems. Some are similar in their impact; others appear inherently different, at least in historical context. We then discuss the details of design of two flight systems, the airborne data acquisition and management system (ADAMS) for the C-141 flying astronomical observatory and the airborne digital data acquisition system (ADDAS) for the CV-990 research aircraft. The major aspects of Ames' operational experience in applying these systems to the solution of problems encountered in the research environment are reviewed. The paper concludes with a discussion of general principles synthesized from this experience that seem particularly relevant to trends in the evolution of intelligent scientific data systems.

PART I

DESIGN PRINCIPLES AND APPLICATIONS TO
FLIGHT SYSTEMS

BASIC CONSTRAINTS OF FLIGHT AND SPACE ENVIRONMENTS

Although the fundamentals of the design of Shuttle or other space data systems are of particular interest, such a discussion is clearly beyond the scope of this work, which is limited to an in-depth analysis of the airborne systems. However, in manned missions such as the Shuttle Spacelab, the environmental constraints are very nearly although not quite the same as those involved in the design of airborne systems. The following factors are illustrative of some of the obvious similarities. For example, large jet aircraft such as the Convair 990 and the Lockheed C-141 have fairly benign environments. In the flight regime, temperatures may vary by about $\pm 5^{\circ}$ C at 25° C, and pressure altitude is normally at about 3 km (10,000 ft) but may vary from zero to 6 km (20,000 ft) for short intervals. Mechanical vibrations and shocks in flight are entirely compatible with most normal laboratory instruments, as can easily be verified by one who has flown on a jet aircraft, but some attention must be paid to unusual G forces encountered in aircraft maneuvers, atmospheric buffeting, and takeoff/landing operations. Provisions must also be made for crew safety in emergency situations. Equipment must be solidly mounted or have the equivalent of seat belts to secure them against these G forces.

On the other hand, there are some notably different constraints in aircraft and spacecraft. For example, jet aircraft are capable of carrying tremendous payloads economically, and can produce very large amounts of electrical power to supply equipment. These are two of the main areas of difference between the airborne and the space environment; operationally, perhaps the more significant is the limitation of electrical power in a spacecraft. For approximately the same payload, the electrical power available to Shuttle Spacelab experimenters is of the order of 5 kVA, whereas approximately 20 kVA is available in both the CV-990 and the C-141. For the same payload weight, moreover, the vehicle operating cost is far greater in the space mission than in an airborne mission. Thus, conservation of weight would effect important economics, allowing more science per pound, or per dollar, if such a crude analogy is permitted.

There is also a great difference in the psychological climates of the space and airborne missions. This difference has been built up over the years since Sputnik as a kind of "religion of rigorous concern for success." The primary tenet of this creed is R&QA (reliability and quality assurance), and degrees of perfection are measured in terms of MTBF (mean time between failure). This psychological climate drove the cost of previous space systems very high. Now, however, we have men in space in vehicles having the capacity to carry spares and to return to earth for new supplies or replacement parts. Thus, we can more nearly approach the philosophy of a tolerable level of correctable error that has been so much a part of the success pattern of airborne investigations.

AIRBORNE DATA ACQUISITION AND MANAGEMENT SYSTEM (ADAMS)

System Design Guidelines

The C-141 is a large military jet transport aircraft, which provides a platform for a 91-cm reflecting telescope, inertially stabilized and ideally suited to astronomical measurements in the infrared spectrum. The capability of flying at altitudes much higher than ground-based observatories makes this platform second only to space systems for eliminating the interfering effects of atmospheric water vapor in the observations.

Guidelines for the design of the airborne data acquisition and management system (ADAMS) were defined primarily by the functions to be performed, within rather broad constraints on physical size, power consumption, and flight operations parameters. From the first, the interactive role of the system was recognized, wherein the computer in response to programmed or real-time instructions from the operator (experimenter) would predict the optimum aircraft flight path and, when implemented, would orient the telescope for astronomical observations and track the selected target.

In general terms, the priority function of the system was to acquire and record high-quality data from diverse experiments in the science of infrared astronomy, and to do so in a convenient and reliable manner over the long term. To this end, the design emphasis was on commercially available components of standard design that could be readily repaired or replaced. Such units were combined to minimize functional dependence on one another, and to provide redundant functions wherever possible, so that failure of one part would not destroy the effectiveness of the others.

Additional guidelines required that the data system be expandable to meet future requirements and that it be compatible with other systems - namely, the data system on board the CV-990 research aircraft, and the larger ground-based computer systems at the Ames Research Center. Furthermore, the system was to accommodate rapidly to changes in experiments from mission to mission, and to variations in experiments within the same mission. The use of modular hardware and software was recommended as a primary aid in achieving these design goals.

The data system was required to handle high-speed analog and digital data inputs (e.g., 15-bit precision at 10,000 wps), perform specialized computations such as co-adding and Fourier transformation, display diagnostic and quick-look information on experiments, and provide a post-processing capability sufficient to diagnose experiment faults and evaluate critical parameters between flights. Finally, telescope control, collection of avionics data, high-speed data acquisition, and computation of flight profiles were to be coordinated in flight to optimize scientific yield in the available flight time.

In addition to the airborne data system, a ground-based simulation facility was required to support software development and experiment integration. This facility was planned to functionally duplicate the

experiment-related processes of the flight data management system with a practical minimum of hardware, and was to be compatible with the flight data system of the CV-990 aircraft.

System Functions

Data acquisition and recording- The primary function of the ADAMS system is to acquire and record digital data from the main experiment on the telescope. To accommodate a wide variety of experiments, the system is flexible as to data rate, record size, data frame definition, intermediate handling (such as packing), and recording method. The highest priority of the system is to protect against total loss of data or data recording time on a flight. It contains sufficient redundancy to allow for individual component failure without catastrophic effect.

To provide the flexibility required in a multiexperiment environment, data acquisition and recording is performed on a largely autonomous computer essentially dedicated to data-taking tasks. Data are accepted by the computer through an analog-to-digital converter (ADC) and stored on digital magnetic tape. Because the data rate is limited by the tape drive, abundant computing time is available for intermediate processing such as packing, minor conversions, or sync-pulse recognition.

Software for these operations is provided as building blocks which have to be configured appropriately for each experiment. Modules provided include buffered input from the ADC, formatting and buffered output to tape, start/halt control for both acquisition and recording, and other functions allowing various forms of experiment control and data communications. Custom software is generated for each experiment to provide timing and sequence control for the standard modules as well as any intermediate processing required.

Primary experiment performance monitoring- One of the most important advantages of an on-line digital system is that it can provide the experimenter with real-time monitoring of his results. This feedback to the experimenter can enable him to avoid costly errors, discover instrument malfunctions, and generally make the best use of his limited observation time.

The ADAMS system provides several forms of inflight processing for a powerful quick-look capability. First, raw data can be co-added to achieve an improved signal-to-noise ratio.* Second, co-added or raw data can be Fourier transformed to provide frequency spectra for display on a CRT device. Third, current raw data can be displayed on the CRT to check for signal quality. Fourth, special treatment such as windowing or filtering can be applied to the spectra. Finally, calibration data may be displayed for comparison with acquired data.

*Co-adding is the accumulation of data components in an array where the elements of the array represent the sum of a number of similar components of an interferogram or a spectrum.

Software is provided to perform all these functions with the exception of nonstandard "special treatment" functions. The user specifies control parameters for the standard functions (such as display scales) and provides control and timing software for interfacing his data with these functions.

Environmental and engineering parameter recording- Experimenters generally require an accurate record of environmental parameters for post-processing of their data. The C-141 aircraft has a comprehensive set of these parameters available in the Central Air Data Computer (CADC). Also, positional data are available from the C-141 Inertial Navigation System (INS). Data are collected from these and other sources, automatically, at specified intervals. The data are recorded on magnetic tape, as well as displayed on a line printer. All of the software for this data-collecting function is provided, although some of the parameters or functions of this software are transparent (unknown) to the user, and are initiated periodically by a hardware timer.

If any of these parameters is required for intermediate processing of, or co-recording with, primary experiment data, the user can specify a block of the parameters required for his program.

Flight planning and navigation- The C-141 data system is capable of generating a new or altered flight plan in the flight environment, which provides the experimenter with additional flexibility in the use of his flight time. Typical uses of this system function are to lengthen or shorten a segment of the flight to provide more viewing time or avoid wasting time; or to add or delete objects to be viewed, based on changing requirements.

With the aid of the navigator, the computer generates constant-bearing flight paths for correct acquisition and maximum viewing time for single objects. The program runs in an interactive fashion in response to information supplied by the navigator, so that he can optimize the total flight plan and avoid undesirable (e.g., restricted) areas. As a subordinate function, the computer can be requested to monitor the flight's progress via the Inertial Navigation System (INS) and compare it with the current flight plan. Flight progress is displayed periodically for the user.

Registration star chart display- As an aid in acquiring objects on the telescope, the ADAMS creates visual displays of local star fields for registration with the objects viewed on the telescope monitor. The registration images are generated from a magnetic tape digital file of star locations, then displayed on the telescope monitors via a scan-converter device. Sample star fields can also be displayed by the user on a CRT device at scales other than those available on the monitors. The digital file of star locations has been created from the Smithsonian Star Atlas tapes. Many celestial objects are not sufficiently close to stars in the Smithsonian Atlas and require supplemental data for acquisition. An off-line facility is provided for entering this data into the star file to be used in flight.

Offset-tracking support- Two functions are provided to assist the experimenter in the use of the facility's offset-tracking capability. First, the system will search its digital star file for suitable tracking objects,

given the primary object location. The experimenter is given a list of available tracking objects and he chooses the one to use. Second, once the experimenter has chosen the tracking object, the offset tracking parameters required by the wedge control system are calculated and sent to the system that controls the telescope position. The experimenter is thus relieved of computing and entering the parameters by hand.

Raster scan- To provide an accurate scanning mode for the telescope, the system is capable of creating precise biasing voltages for the active tracking system. An interactive program has been devised that allows the experimenter to specify one of several types of geometric scan patterns, and to control the progress of the scan manually.

Experimenter programming support- The system supports special program modules generated by both primary and secondary experimenters. Without greatly changing any of the utility software, it is possible to add experimenter routines for conversion of raw data into engineering parameters for display in character or graphic form on one of several output display devices.

Ground-based simulation and software development- An auxiliary ground-based data system containing many of the same components as the flight system is available for software development and experiment simulation. This system and the flight system (during nonflight hours) can be used for off-line processing. This system can be used to produce copies of experimenter magnetic tapes, create new programs, and collate the Smithsonian Star Atlas tapes with new astronomical data of use to experimenters in flight.

System Hardware

The hardware in the ADAMS system (figs. 1 and 2) is of two types:

- (1) that exclusively dedicated to the use of the primary experiment, and
- (2) that used as a utility to service the secondary experiments, the avionics, and housekeeping functions. The former consists of one multiplex analog to digital converter (MUX/ADC), a 16K core processor (the data processor), two digital magnetic tape transports, and related peripheral equipment. Use of this equipment in acquiring and logging data is largely under the autonomous control of the experimenter. This kind of nearly autonomous operation permits greater flexibility and higher data rates than would otherwise be possible. It simplifies the hardware and software interfacing by permitting the experimenter to develop his experiment on another identical or a similar processor before integration into the system.

Figure 3 shows the relationship between the two types of equipment. A communication channel exists between the data processor and the executive processor, which is a key element of the support and housekeeping components. This permits bilateral software and data transfer under executive control. The hardware of the C-141 data system is designed to provide computing power for a wide range of applications, with a maximum of redundancy for system reliability. Considerable design effort has been devoted to the reduction of software and other development costs by adding hardware to spread out and simplify the software burden.

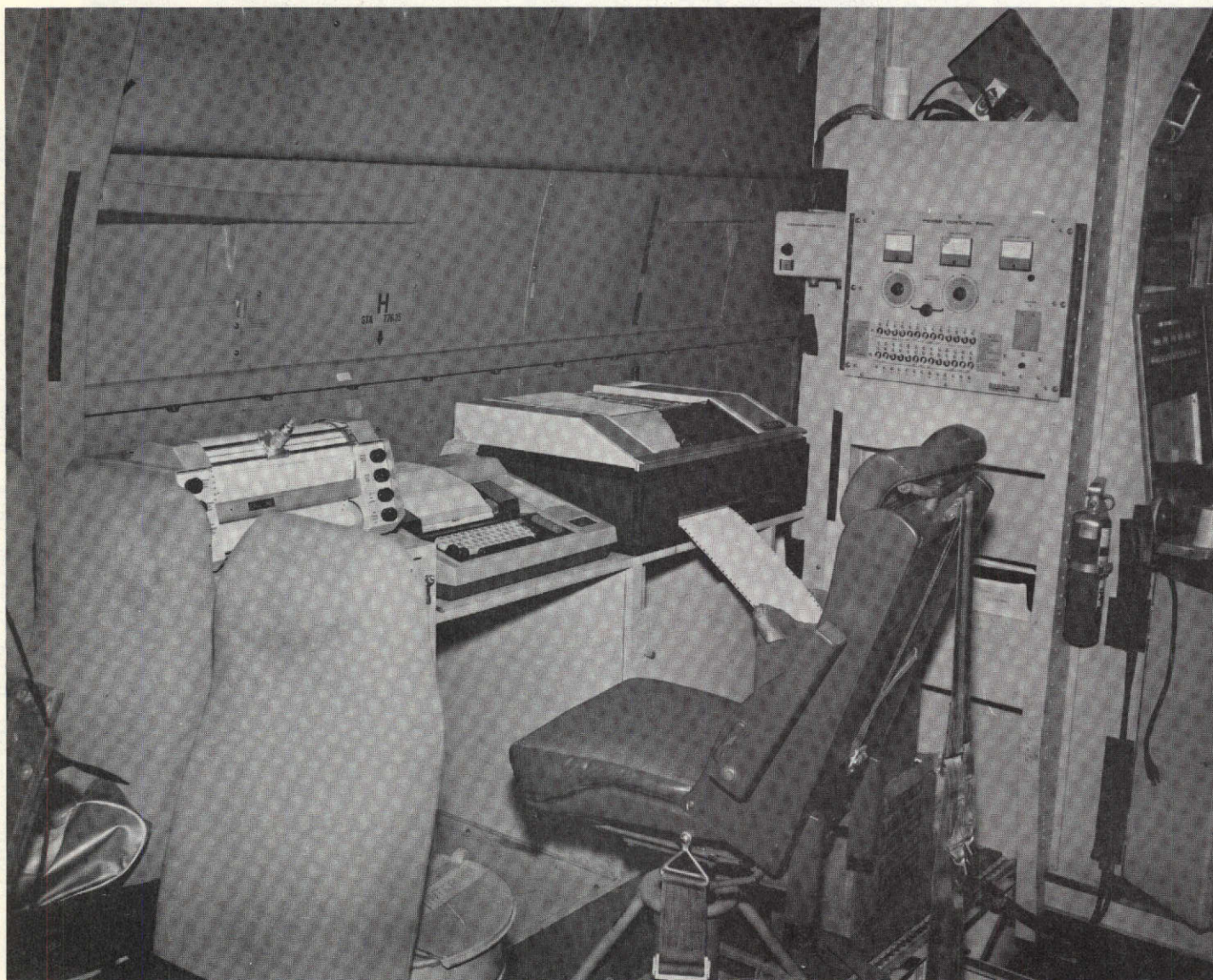


Figure 1.- Operator's console (ADAMS) in C-141 aircraft.

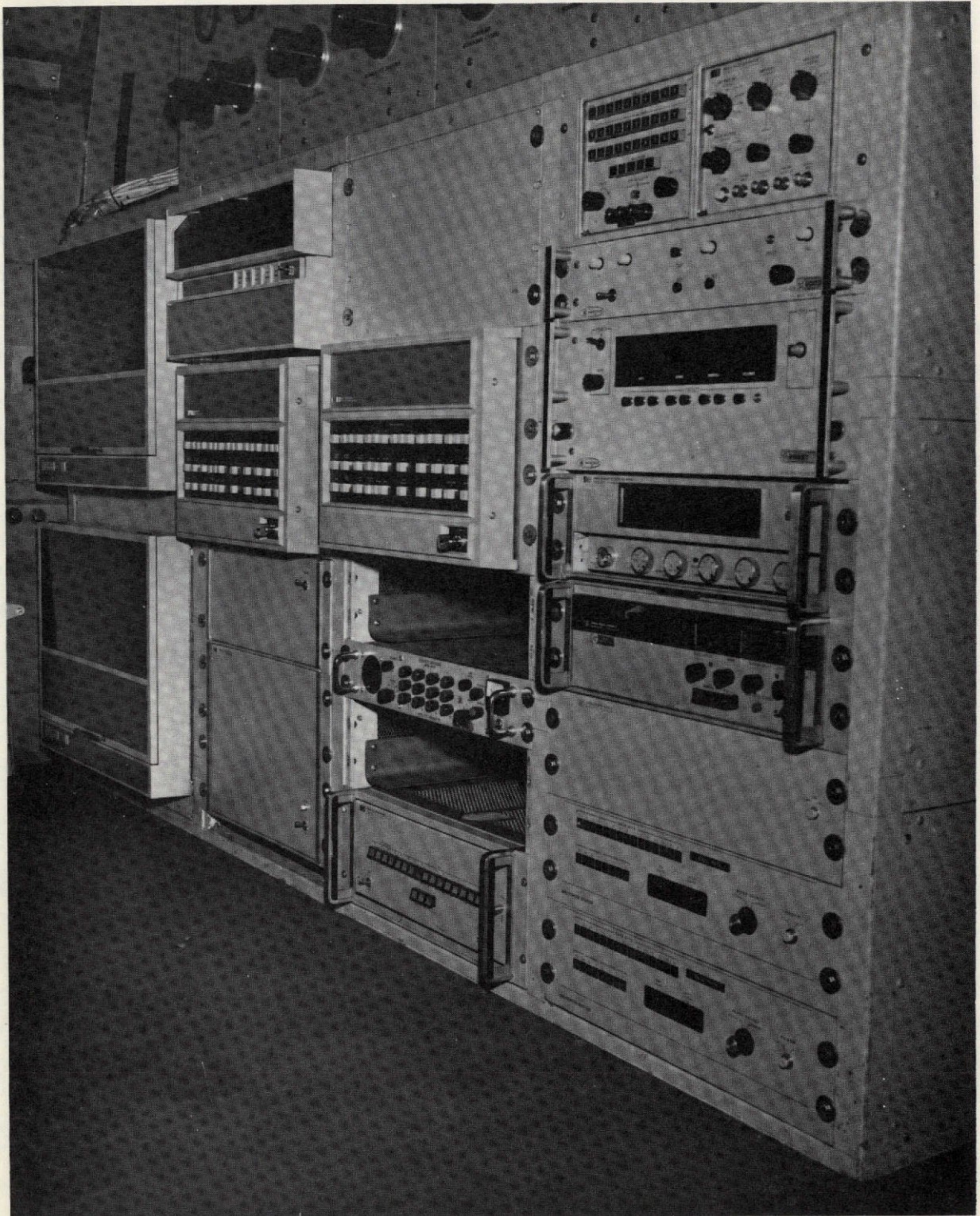


Figure 2.— Aft data system rack (ADAMS) in C-141 aircraft.

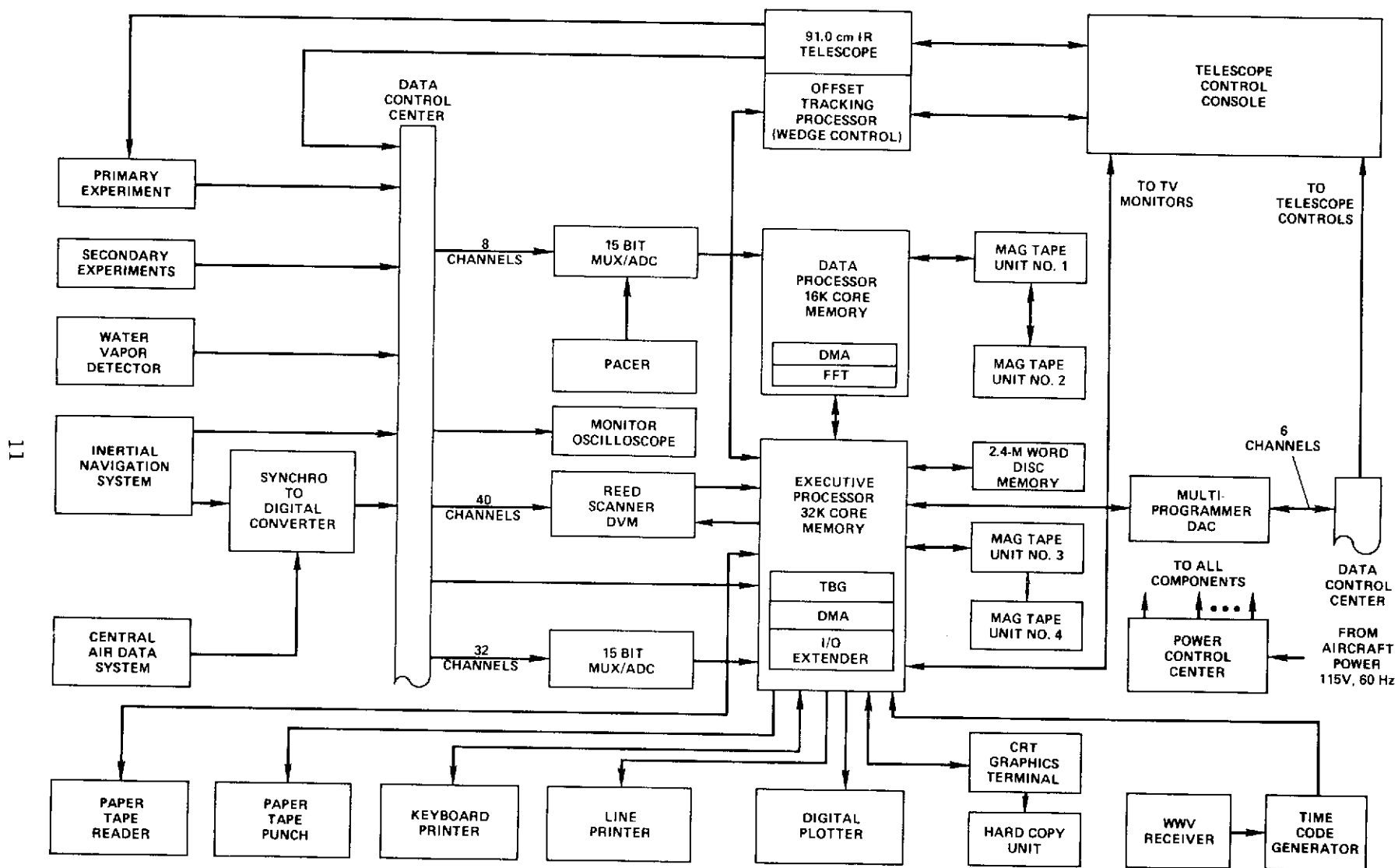


Figure 3.— Block diagram of C-141 data acquisition and management system (ADAMS).

The data processor contains a fast Fourier transform arithmetic unit. This unit is primarily intended to serve the need for performing transforms on interferograms to produce quick-look displays of infrared spectra; it can be used for many other purposes, however, and is available to the experimenter. The experimenter's software is loaded into the data processor from the executive processor. Developed software can be placed in the executive processor in the form of magnetic tape, paper tape, or disc cartridge and then transferred to the data processor.

A second communication channel exists between the executive processor and the offset-tracking processor. This latter unit acts as a controller to drive two optical wedges that deflect the optical axis of the tracking telescope in relation to the main telescope. It also solves the geometric relationships necessary to properly position the tracker in accordance with commands received from the executive processor and initiated by the experimenter or the ADAMS operator under software control. The telescope operations and control loop is completed through the control console shown in figure 4.

The executive processor, containing a 32K word core memory, is used to perform utility functions such as interfacing with the IR telescope, aircraft systems, and secondary experiments, as well as handling most of the input/output equipment used to control system parameters and provide displays and listings. Another function of the executive processor is to support the special requirements for aircraft navigation and for acquisition and tracking of celestial objects.

Data enters the executive processor in many ways. The 15-bit multiplexer ADC is one means of entering relatively high-speed data from avionics and other sources. Another method of entering data is through the reed-scanner digital voltmeter, which is used to interface housekeeping channels and is limited to low data rates up to 40 samples per second. The multiprogrammer digital-to-analog converter (DAC) is equipped with one digital input card through which flag bits can be entered by manual keyboard into the executive processor. Similar inputs can be made through multipurpose duplex registers directly interfaced with the computer.

The executive processor is equipped with a 2.4-Mword disc, which is used to archive program materials and a very limited amount of housekeeping data. For a normal mission, most of the housekeeping data are recorded on one of the two digital magnetic tape units attached to this processor. The other tape unit constitutes an archive of visible star data as an aid to celestial object acquisition and in navigation. Other peripherals of the executive processor serving utility functions include a video generator, paper tape punch, digital clock, line printer, hard-copy unit for the CRT, and a monitor oscilloscope. A complete equipment list is given in table 1.

System Software

The C-141 data management system is a real-time, dual-processor system with both interactive and automatic processing requirements. The general

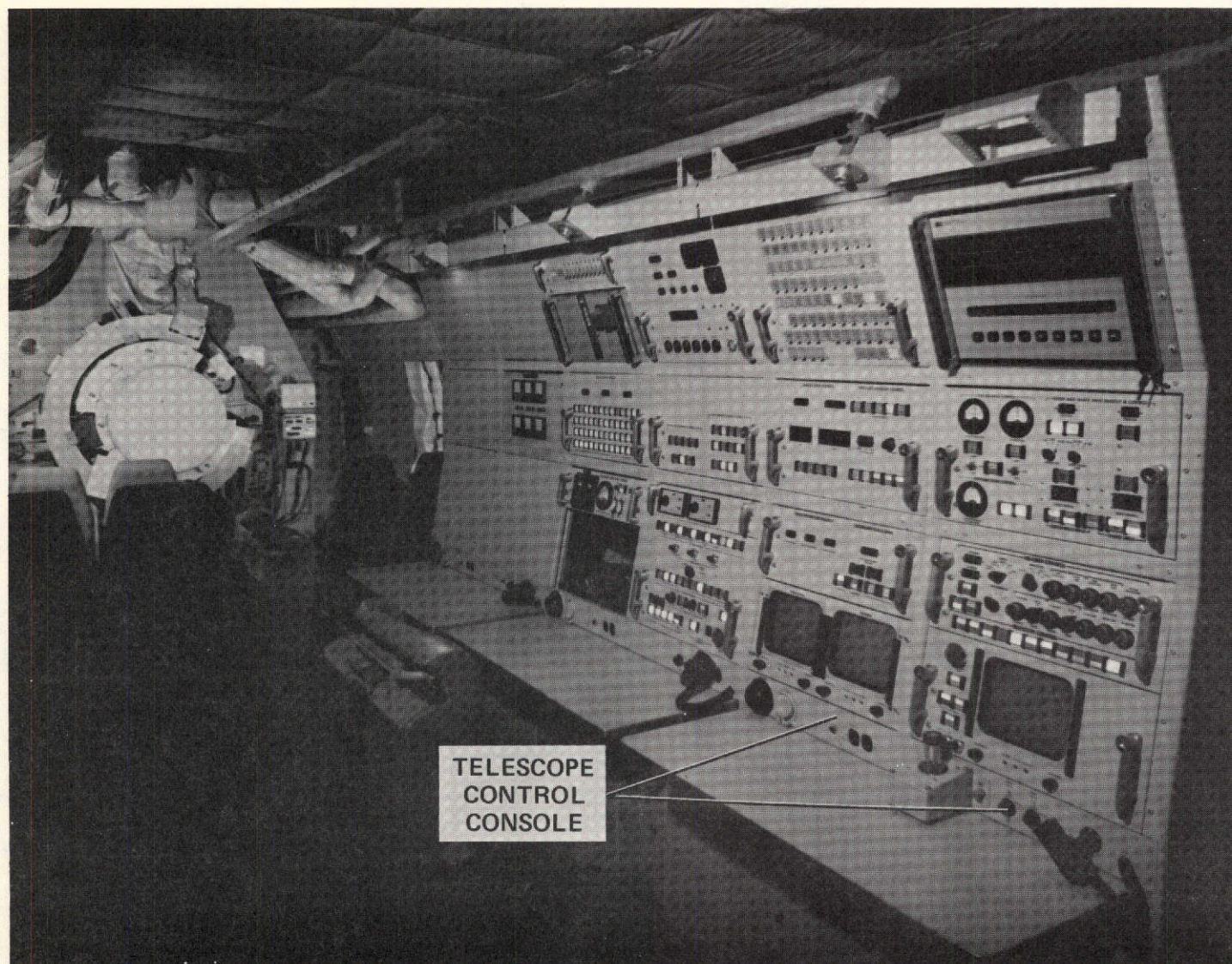


Figure 4.— Telescope control console in C-141 aircraft.

Table 1. Equipment inventory for the ADAMS

Data Processor

Core memory; 16K, 16-bit words (expandable to 32K)
 Direct memory access unit (DMA); transfer rate 1M-word/sec.
 Magnetic tape subsystem 1; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi), 15-kHz rate
 Magnetic tape drive 2; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi), 15-kHz rate
 Multiplex A/D converter (MUX/ADC); 15 bit, 8 channels, 18-kHz max. sampling rate
 Interface for MUX/ADC
 Pacer subsystem
 Fast Fourier transform arithmetic unit (FFT); 2048-word capacity
 Interface parallel duplex register

Executive Processor

Core memory; 32K, 16-bit words
 Time-base generator (TBG)
 Direct memory access unit (DMA)
 Interface for executive processor (2)
 I/O extender
 DMA for I/O extender
 Interface parallel duplex register
 Multiplex ADC; 15-bit, 32 channels, 45-kHz max. sampling rate
 Keyboard/printer
 Digital plotter
 Line printer; 300 lines/min or better, 132 characters/line
 Graphics terminal (CRT); 300 characters/sec
 Video generator
 Hard-copy unit; 20 sec or less copy time
 Disc subsystem; 2.4M-word capacity
 Magnetic tape subsystem 3; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi)
 Magnetic tape drive 4; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi)
 Paper tape punch and interface; 75 characters/sec
 Paper tape reader and interface; 500 characters/sec optical
 Multiprogrammer DAC; 6 channels, 12-bit binary input, ± 10.24 Vdc output
 Input card for multiprogrammer
 D/A card (6)
 Interface kit for multiprogrammer
 Radio receiver for National Bureau of Standards time signal from station WWV
 Time-code generator
 Reed scanner
 Digital voltmeter (DVM); ± 10 -Vdc input
 Reed scanner/DVM interface, data source card
 Reed scanner/DVM interface, program contract card
 Reed scanner/DVM interface, scanner controller card
 Monitor oscilloscope
 Syncro-to-digital converter (SDC); 4 channels, 0 to 10-Vdc output
 Syncro-to-digital converter (SDC); 3 channels, ± 10 -Vdc output

performance requirements are for a high degree of reliability, flexibility, and simplicity of operation. To meet these requirements, the system has been designed to include elements of time-sharing, multiprogramming, and process control systems. The system has three on-line modes of operation: initialization, command, and automatic. These "modes" can run concurrently, although the work they perform is essentially separate. The system also is capable of running off line as a conventional computer, using conventional operating systems and languages such as Fortran IV. Figure 5 is a functional block diagram of the system software showing the basic relationships among the various modules. Software development consumed 3 to 4 man-years of effort to achieve flight status.

Initialization mode-The initialization mode occurs at the outset of each flight. It is supported by a special program designed specifically to establish the configuring parameters for the use of the system by a particular experiment. This program is designed to allow the user the widest possible control over the work that the system is to perform while avoiding new programming that may cause unpredictable delays due to the generation of subtle errors or "bugs" always encountered in new software.

The initialization program is interactive, collecting desired data via dialogue with the experimenter on the CRT terminal. A step-by-step procedure allows the user to specify or permit default conditions for all of the functions and their associated control parameters he intends to use. The information entered through this program includes:

1. Standard features on data computer
2. Spectral displays on CRT, scales, display rate, etc.
3. Special reduction features for spectral data
4. Secondary data acquisition on executive processor
5. List of housekeeping and secondary data to be printed, with the printing format
6. Initial values for staple functions such as navigation

The initialization mode does not run concurrently with the other modes when it is used to initialize the system. It can be re-entered later, however, to make changes to the system configuration and, at that time, it will run concurrently with the automatic mode.

In addition to its role in initializing the system, the initialization mode program loads the appropriate software into the data processor, loads software into the off-set tracking processor, begins the operation of the automatic mode, and enables the operation of the command mode. At the end of the operation of this mode, the program no longer occupies the core storage of the system. It can be reloaded and reexecuted, however, under control of the command mode.

Command mode-The command mode represents the software interface between the data system on the one hand, and the experimenter, navigator, and operator on the other. It is the means by which the users of the system can command it to perform the various tasks that are not done automatically, such as star plot generation or flight planning. Table 2 lists the commands available to

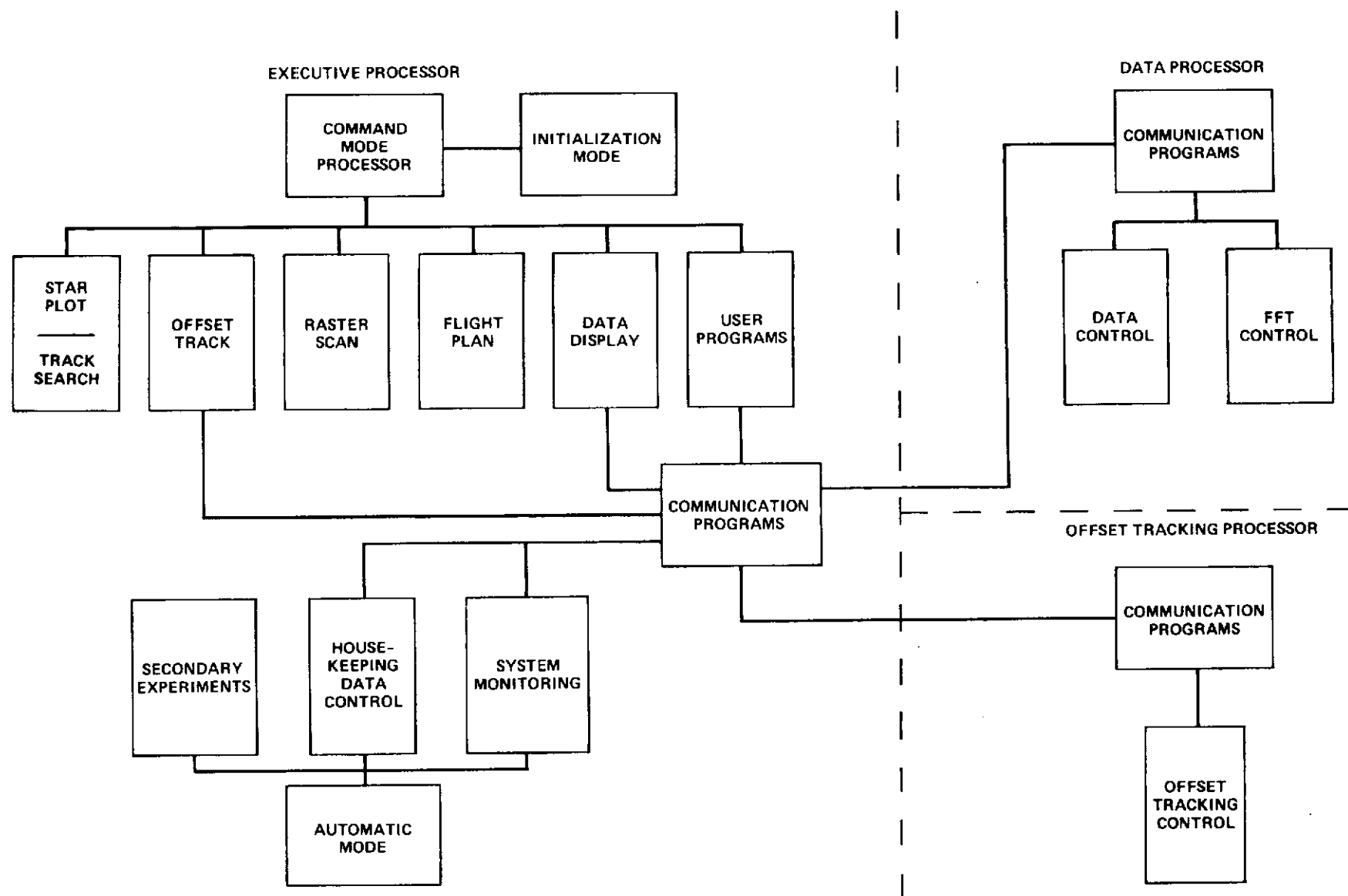


Figure 5.— ADAMS software block diagram.

Table 2. Command list (with mnemonic command codes)

Keyboard Printer Command List (Operator or Navigator)	CRT Command List (Experimenter)
FL - Generate a New Flight Plan ST - Store Flight Plan DU - Dump Flight Plan WP - Check Way Points SP - Start Printout HP - Halt Printout SS - Start System HS - Halt System RC - Reconfigure Devices TD - Take Device Off Line PD - Place Device On Line	OT - Start Offset Tracking System PL - Generate Registration Star Plots SD - Start Data Acquisition System HD - Halt Data Acquisition System SR - Start Recording HR - Halt Recording EF - End File on Magnetic Tape CM - Enter Comment Line DP - Display Primary Experiment Data DR - Display Primary Experiment Raw Data EX - Execute Experimenter's Program RI - Re-Initialize RS - Perform Raster Scanning

the user. The commands are sent to the system by the users from either of two terminals. An interrupt initiated at the terminal causes the computer to read a command from that device. The command is then decoded and used to select an appropriate service routine from the program library. A group of such routines runs concurrently with other system functions and even with other command routines, so the routines must be scheduled on a priority basis.

The command set itself is divided into two groups; one for the experimenter and one for the operator and navigator. This separation allows the essentially independent requests of the users to be entered simultaneously, so that there is no conflict in terminal utilization. If one terminal fails, however, all commands may be entered through the other one.

As mentioned above, the command service routines run concurrently with other system functions. A carefully devised system of priorities prevents delays to time-sensitive programs and conflicts for I/O devices. Normally, the users are not able to see degradation in service of their commands from regular system functions. Highest priority is assigned to housekeeping data acquisition, which runs periodically and transparently to the user. Command service routines have the next priority. Longer commands, such as navigation and flight planning, can be interrupted by shorter commands, such as Halt Recording. The entry of any command interrupts any service routine, but the service of the command will wait until no higher priority program is active. Lowest priority is assigned to automatic data display to avoid I/O device conflicts.

Automatic mode- The automatic mode programs are those that operate independently of the operator or experimenter. These programs are initiated by the system clock or by events in the system. They do not require the intervention of the users, and their execution is normally transparent to the users. The functions of the automatic mode include:

1. Housekeeping data acquisition, recording and printing
2. Communication with the data processor
3. Hardware performance monitoring
4. Way point checking of flight plan progress
5. Spectral data displays
6. Raster-scan control

In addition to these executive resident functions, the data processor operations can also be considered to be in the automatic mode in that these programs generally operate without user intervention. The data processor programs also may make use of blocks of data from the executive processor, and the executive processor will accept spectral data and hardware status data from the data processor. All of this communication is handled in the automatic mode.

The automatic mode operations are started at the end of the initialization mode, which ordinarily will be the beginning of a flight. Automatic mode operations continue unless the system is halted by the operator. Certain automatic operations, such as spectral displays and way-point checking, can be started or stopped independently of the other functions.

Automatic operations are executed concurrently with command programs and initialization programs (during reconfiguration). The automatic programs are generally short and do not create I/O device conflicts; therefore, they usually execute with high priority.

AIRBORNE DIGITAL DATA ACQUISITION SYSTEM (ADDAS)

Precursor Development

A precursor to the present ADDAS system was assembled and flown in the original Ames CV-990 research aircraft between 1970 and 1973. Impetus for the development of this early system originated with the user community, in particular to enable the simultaneous, time-coded recording of data from several closely related experiments in the payload of a single-purpose mission. Operational experience with the precursor system for airborne data management provided the essential ingredient in the successful development of both the ADAMS and ADDAS systems described in this paper.

The heart of the precursor system was a data processor with a 16K core memory. Peripheral units were provided for input of analog and digital data from experiments, flight parameters from aircraft avionics, precise timing signals from the National Bureau of Standards radio station WWV, and experimenter's comments via teleprinter. The data system could perform a limited amount of on-line data processing, in addition to recording in several media and displaying selected flight and experiment parameters on closed-circuit television. A block diagram of the precursor data acquisition system is given in reference 1 (fig. 7-A).

Experience gained with the earlier data acquisition system served to guide the design of the present ADDAS. In particular, it was found undesirable to have all data management functions resident in a single processor, where a fault in a secondary unit could interrupt the primary data acquisition function while repairs were effected. In practice, the functional redundancy was not sufficient to assure an uninterrupted data record, and individual experimenters often furnished their own backup recorders for critical situations. The size of the precursor system (16K memory) and the rate of acceptance of high-speed data (18 kHz) were also limiting factors, again requiring that some experimenters record their results independently. Even so, on major missions the data system was nearly always used to full capacity.

Insofar as possible, both the hardware and software of the precursor system were in modular form to facilitate component maintenance and to minimize rewrite for the specific data handling requirements of successive missions. Software development effort was estimated at two-man-years. The updating of utility subroutines for a specific mission took about one man-day, exclusive of special processing for new experiments; however, this activity required system regeneration for each new mission, which resulted in the generation of subtle errors and hence reduced software reliability.

The precursor system had some capability for postflight data processing and program changes to accommodate unexpected research results. Nearly all experimenters relied on time-correlated flight parameters recorded by the system, over half relied on accurate recording and printout of their experimental data, and about 40 percent required some inflight data processing (ref. 1). Use of the system increased steadily as its capability and flexibility were developed over a period of several years; the user community recognized its primary functions of accurate data acquisition and time correlation with data from other experiments or with flight parameters.

On-line data processing was more limited both in quantity and in depth, reflecting not only the capacity of the data processor but also the experimenter's preference for local data acquisition units that gave continuous, real-time verification of data quality, as well as the availability of ground-based hardware for postflight evaluation of results.

Ground-based simulation of experiment hardware and software performance was accomplished primarily on board the CV-990, a procedure that required an intense application of manpower during final preparations for a mission and was clearly recognized as an undesirable constraint to optimum utilization of the system.

System Design Guidelines

Galileo II is a CV-990 commercial jet aircraft providing a second-generation airborne research laboratory used as a common platform for earth observations, astronomical observations, and similar scientific and engineering measurements. The aircraft environment of Galileo II has the advantages of permitting the simultaneous operation of as many as ten experiments constructed of normal laboratory apparatus, each operated by a scientist intimately familiar with it. The environment is relatively benign, and therefore compatible with commercially available minicomputers and peripheral components.

A typical mission carries several experiments related to a single scientific discipline such as hydrology, meteorology, or earth science, and it is possible to benefit by the synergism that results from exchange of data among the experiments, particularly if this exchange can be implemented by the data system. For this reason, a serious effort has been made in the system architecture to permit several scientists to interact with a common data base in real time and process these data adaptively as the experiments progress.

A mission may consist of several flights per week, for one to four weeks, after which all or most of the experiments will be removed and replaced with new experiments in preparation for the next mission. The data system therefore must be flexible enough to change configuration rapidly. These demands can easily be met with the Airborne Digital Data Acquisition System (ADDAS) discussed in this section.

System Functions

The Galileo II airborne data system is the critical part of the larger information processing system that begins with the data sensors on the aircraft and ends with the publication of scientific results. It bears the major responsibility for acquisition and recording of high-precision data of a quality that justifies the effort and expense of further ground-based data reduction so necessary for scientific analysis and interpretation. The primary function of the system is to acquire and record high-quality data from the experiments and from the avionics, which give flight status and housekeeping parameters. Recordings are made on digital magnetic tape during a flight, and copies of this tape are distributed after each flight to the community of users.

The system produces a number of displays of vital signs for quick-look verification of performance to guarantee data quality. These displays give the experimenters a feel for how their individual experiments perform and how the mission is progressing as a whole. The system also permits experimenter interaction with the data base in real time, as noted earlier, enabling experimenter preprocessing of data samples, correlation of data from experiments and avionics, and diagnosis of doubtful data streams. Primary data are recorded on digital magnetic tape. Secondary output media, produced by a listing machine and plotting equipment, are also used for quick-look and diagnostics. A typed log of each flight, annotating events of interest, is recorded with the data and aids in reconstructing the flight situation and identifying unusually interesting data events. The log is entered into the system through a keyboard by the mission stenographer.

The data system controls experiments requiring adaptively computed inputs in response to a change in experiment or environmental parameters. One example is the computation of ground speed per unit altitude. This information is supplied in analog form to control earth-observations camera film speed. The system also synchronizes all avionics and experiments according to a master clock and provides many forms of digital time code and time displays for various purposes. Since time is the independent parameter for all experiments, it is used as the basis for correlating all control, monitoring, and logging functions. Processes within the system are timed and controlled to an accuracy of better than 1 msec.

System Hardware

Figure 6 is a block diagram of the hardware configuration of the Galileo II data system, consisting of a complex of minicomputers, peripherals, and ancillary peripheral equipment. It illustrates the relationship between the two processors - the data processor, which is used mainly for data logging; and the executive processor, which performs most of the other system functions, including managing peripherals and experimenter interaction.

Data originating in scientific experiments normally are in analog and digital form. The analog data are of two types: (1) high-speed experiment data, which enter the data processor through one of two redundant 15-bit

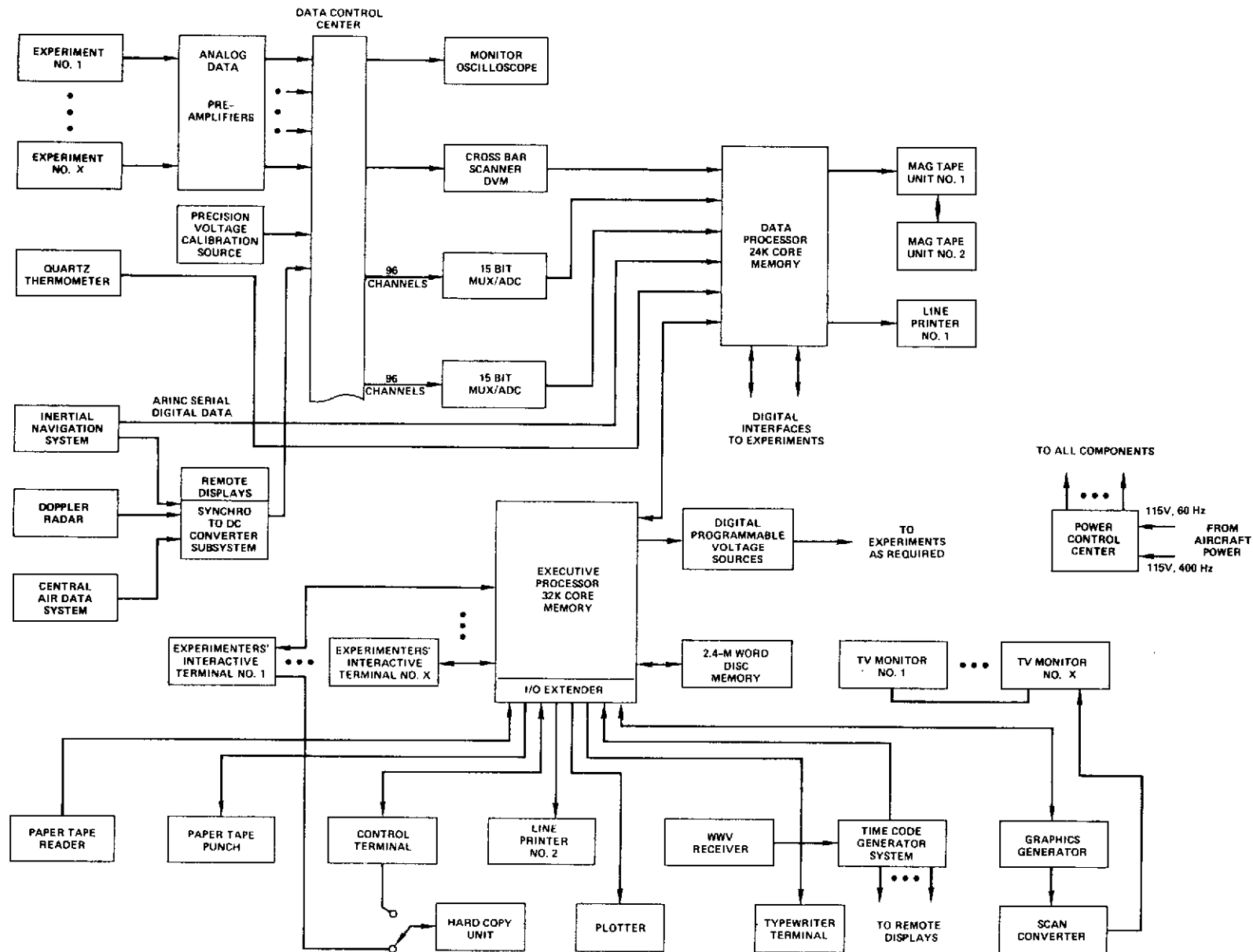


Figure 6.— Hardware configuration of Galileo II data system (ADDAS).

analog-to-digital converters; and (2) low-speed housekeeping data, which enter through the crossbar scanner digital voltmeter (DVM). All signals of this type can be monitored at a central patch-panel located in the data control center. For signals requiring amplification, high-precision analog preamplifiers with noise-filtering capabilities are normally installed close to the sensor signal source.

Digital interfaces to the experiments are made through the input/output channels of the data processor. This is normally done through controllers and data interface cards that are standard accessories to the computer; under special circumstances, however, it is possible to install custom interfaces designed and fabricated by the experimenter. Aircraft flight parameters enter the data system from the CADC, the INS, and the Doppler Radar System (DRS) through synchro-to-digital converters and directly in digital form. The synchro information is first converted to dc and then to digital form in the multiplexer ADCs. A special custom interface to the processor is provided for digital data from the INS. INS data on longitude, latitude, true heading, and other flight parameters, are updated every 1.6 sec and incorporated by software into the main data stream. Other data enter the data processor through the communications link with the executive processor.

After entering the data processor, data are formatted and merged before being recorded on a 9-track digital magnetic tape at a density of 315 bytes per cm (800 per in) and 115 cm per sec (45 in/sec), giving a maximum practical word rate of approximately 13,000 wps.

The executive processor is equipped with a dual-cartridge disc memory system, which permits it to operate like a miniature computations center with multiprogramming capability. It can be used to assemble Fortran- and machine-language programs to interact with the data processor and the experimenter's interactive terminals, and for many other functions discussed in the next section (software).

Data enter the executive processor through the communications link and through the time-code generator. Control signals and comments enter through the control terminal, the experimenter's interactive terminal, and the typewriter terminal. Software and data can also be entered through the medium of paper tape via the paper tape reader, or through the replaceable cartridge of the disc memory system. The time-code generator is the heartbeat of the system, providing inputs to the computers and other components of the system synchronized with universal time by a WWV receiver calibration link. The generator also provides time displays throughout the aircraft.

Data outputs from the executive processor are produced on the line printer and the XY plotter, and displayed on television sets distributed throughout the aircraft as selected flight and experimenter parameters. In addition, the hard-copy unit is capable of recording graphical and alphanumeric information from the CRT control terminal and the CRT experimenters' interactive terminals. Digital-programmable voltage sources are used to output dc voltages for experiment process control.

It is a major objective of the data system to survive equipment failures, and dual hardware redundancy has been designed into the architecture for this

reason. Although each component is necessary for a full operating system, any one of the computers, magnetic tape transports, ADCs or line printers could fail, and the basic data logging function would survive with only minor degradation. Many other types of functional redundancy are possible through reprogramming software, patching, and interchange of identical interfacing circuitry. As we gain experience in system use, the more important survival configurations will be preprogrammed and made available under software control. Table 3 lists the equipment for ADDAS; the arrangement of subsystems in standard aircraft racks is illustrated in figures 7 through 13.

System Software

Because of the changing nature of CV-990 missions, the data system must be reconfigured readily and reliably. Certain functions of the data collection process must be protected from accidental experimenter intervention. These problems can be solved only through a judiciously selected and meticulously developed software set. System software must support a multitude of tasks such as initializing, data logging, data display, and experimenter interaction. It must also coordinate the two computers and peripherals attendant to each. For these reasons, we have selected two coexisting software operating systems, one for the executive processor and one for the data processor, integrated by means of a communications link and functioning in a multiprogramming environment.

The first operating system installed in the executive processor is a real-time executive, disc-based system. It has the capability of core- and disc-resident modules operating in a timesharing mode to perform functions simultaneously or sequentially on command of the control terminal. Within this environment, programs or software modules have been written to initialize the data system, arrange formats, and produce output displays, listings, and plots. The environment supports assembly language, Fortran IV, and a "Basic" interpreter.

The second system is a fairly low overhead core-centered "Basic Control System" operating in the data processor. This system supports machine-language modules developed in the executive processor and installed using a cross loader through the communications link that connects the two processors. All computer-to-computer transactions take place through this link.

Initialization of the ADDAS is similar to that of the ADAMS discussed earlier and is performed by a program operating interactively to ask the operator to specify channel assignment, data rates, and formats for configuring each mission-specific software set. The program permits modifications to the data to be made in Fortran or assembly language for display of engineering parameters. During initialization, no other simultaneous software functions are normally permitted within the executive processor. After initialization, the data processor is cross loaded and can be run autonomously. Re-initialization and program modification during a flight is possible, but other functions within the executive processor must temporarily be suspended. The initialization process makes it possible to gather INS and other house-keeping data, to produce permanent records on magnetic tape, and to display

Table 3. Equipment inventory for the ADDAS

Data Processor

Core memory; 24K
 Magnetic tape subsystem 1; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi)
 Magnetic tape drive 2; 9 track, 115 cm/sec (45 ips), 315 bytes/cm (800 bpi)
 Multiplex A/D converter (MUX/ADC); 15-bit, 96 channels (2)
 Crossbar scanner/digital voltmeter
 Line printer 1
 Data control center (patch panel)
 Voltage calibration source
 Precision analog preamplifiers with variable bandwidth LP filter
 Quartz thermometer
 Monitor oscilloscope
 Inertial navigation system (INS) interface
 Synchro-to-dc-converter system

Executive Processor

Core memory; 32K
 Disc storage; 2.4M-word, dual cartridge
 Voltage calibration sources
 CRT control terminal (character and vector)
 CRT experimenters' interactive terminals (character and vector)
 Line printer 2
 Power control center (patch panel)
 Drum plotter
 Paper tape reader and punch
 Typewriter terminal
 Digital-to-television converter (graphics generator/scan converter)
 Hard-copy unit
 Time-code generator
 WWV receiver
 TV display monitors

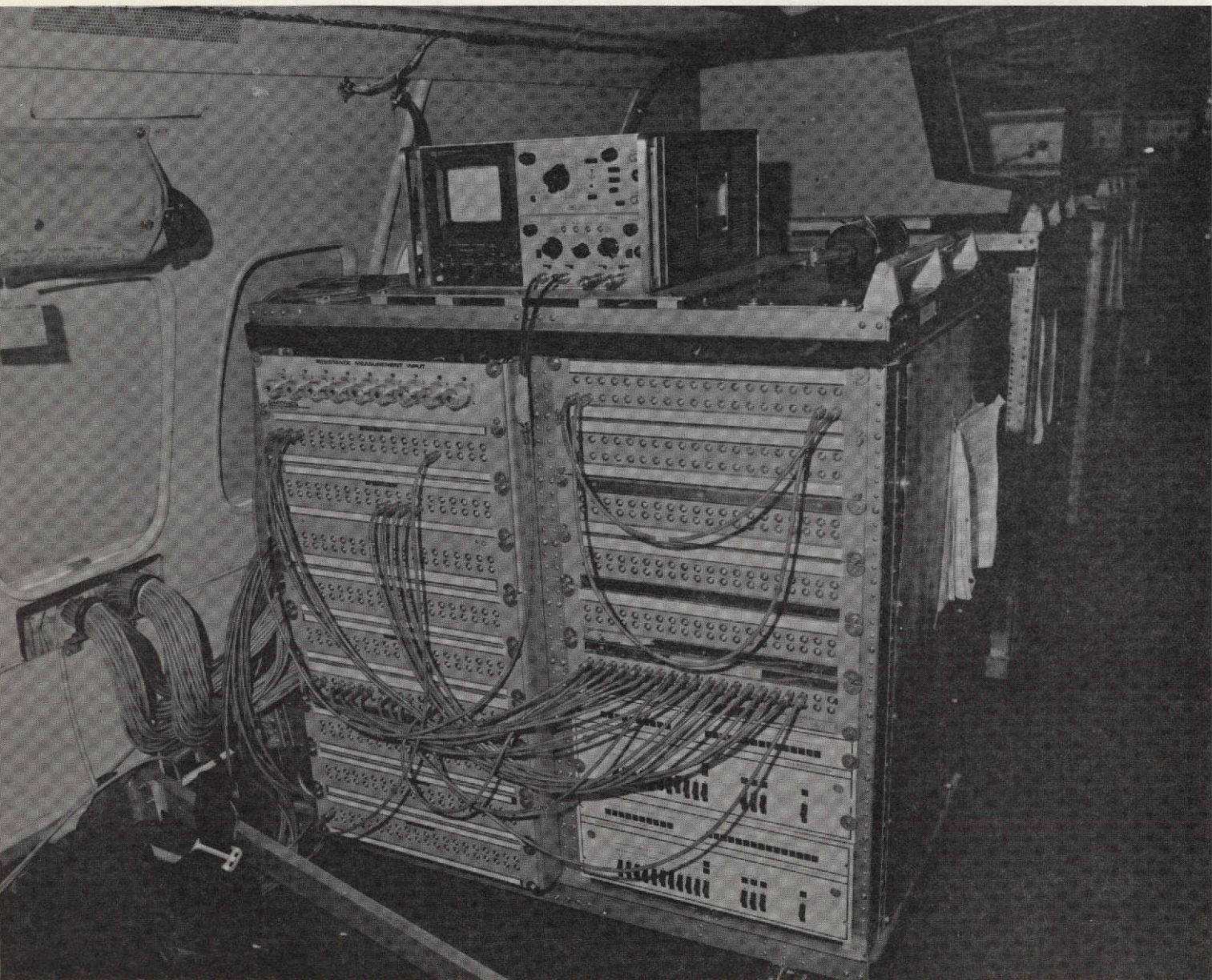


Figure 7.— Data control center (ADDAS) in CV-990 aircraft.

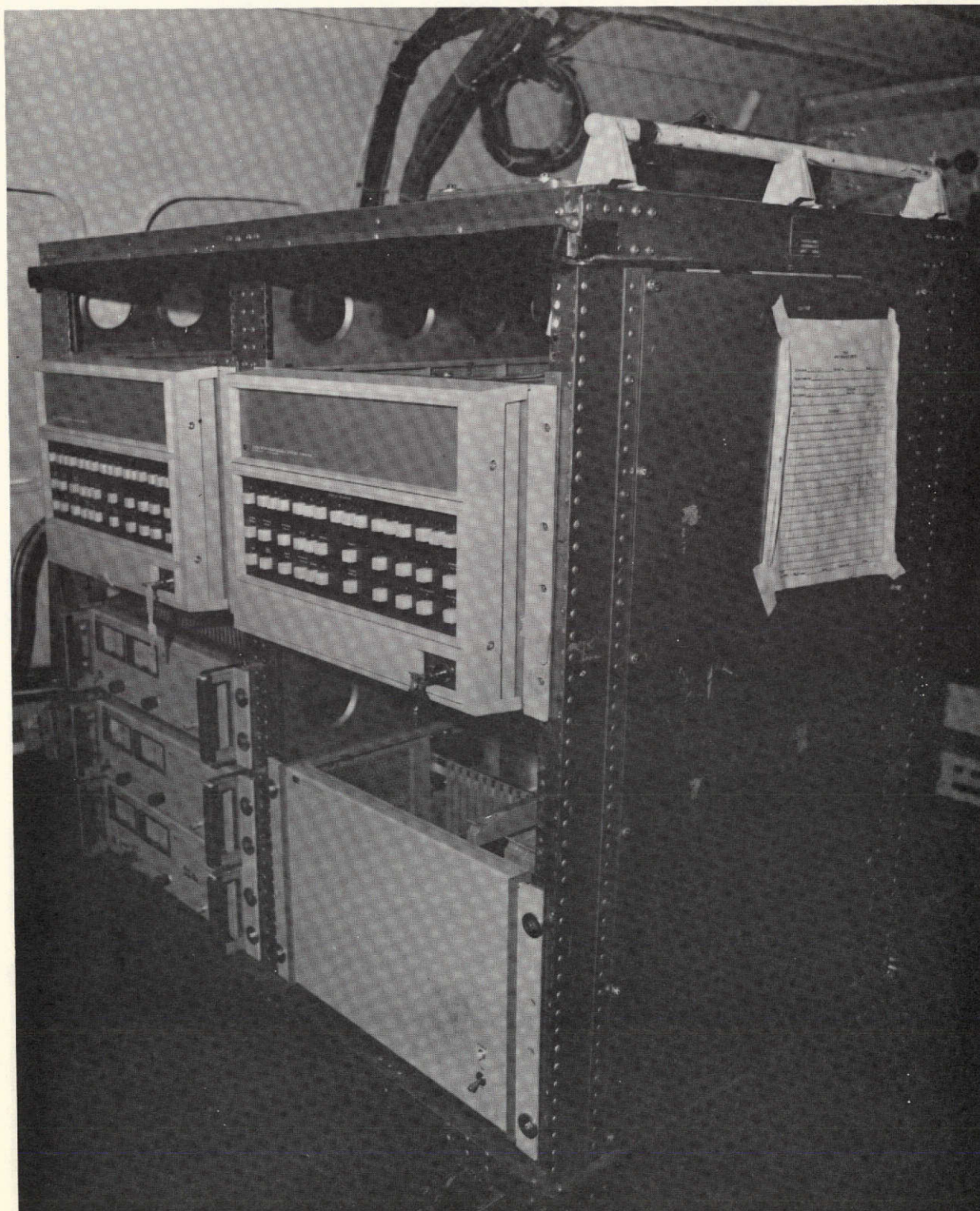


Figure 8.— Executive and data processors (ADDAS) in CV-990 aircraft.

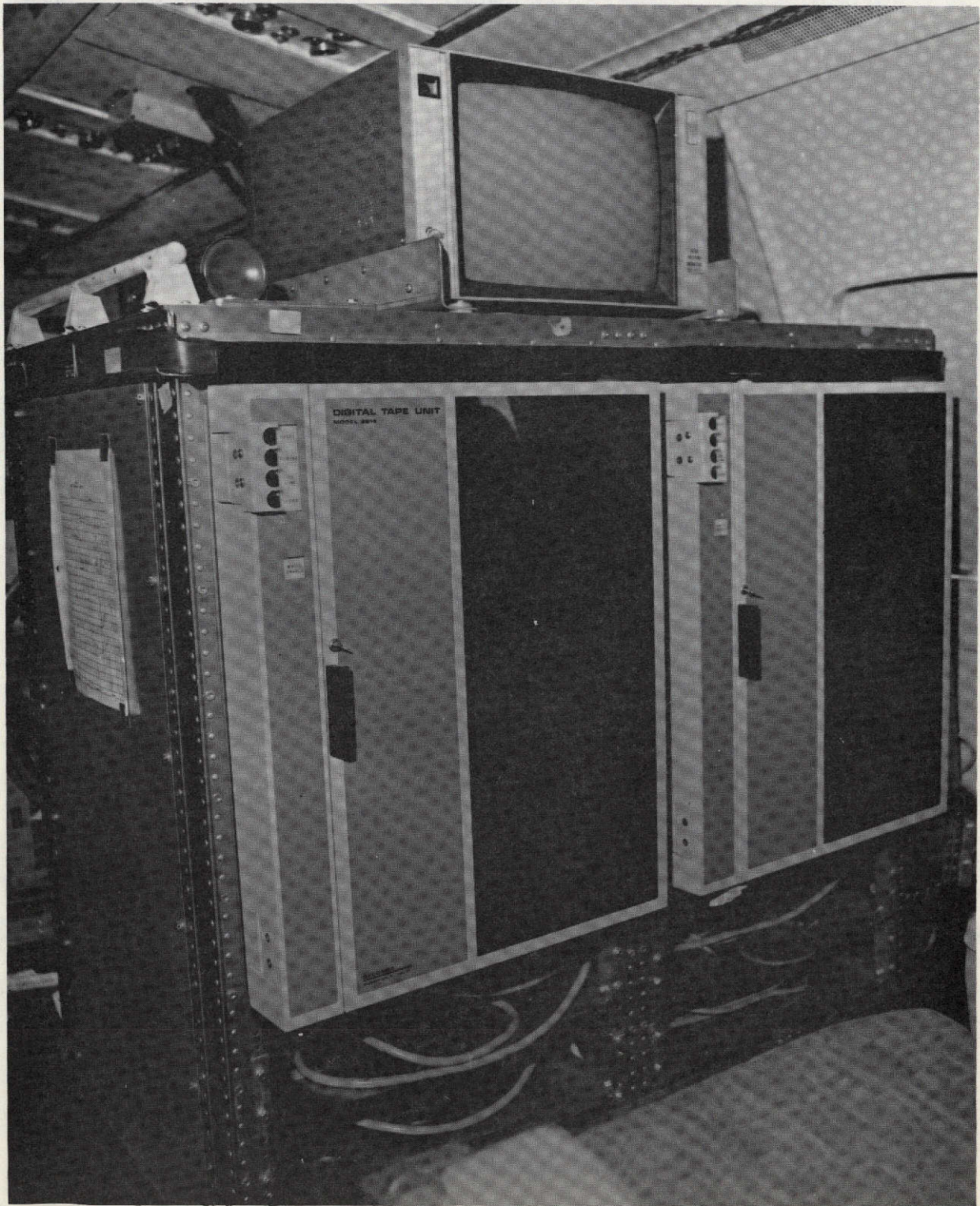


Figure 9.— Magnetic tape recorders and TV monitor (ADDAS) in CV-990 aircraft.

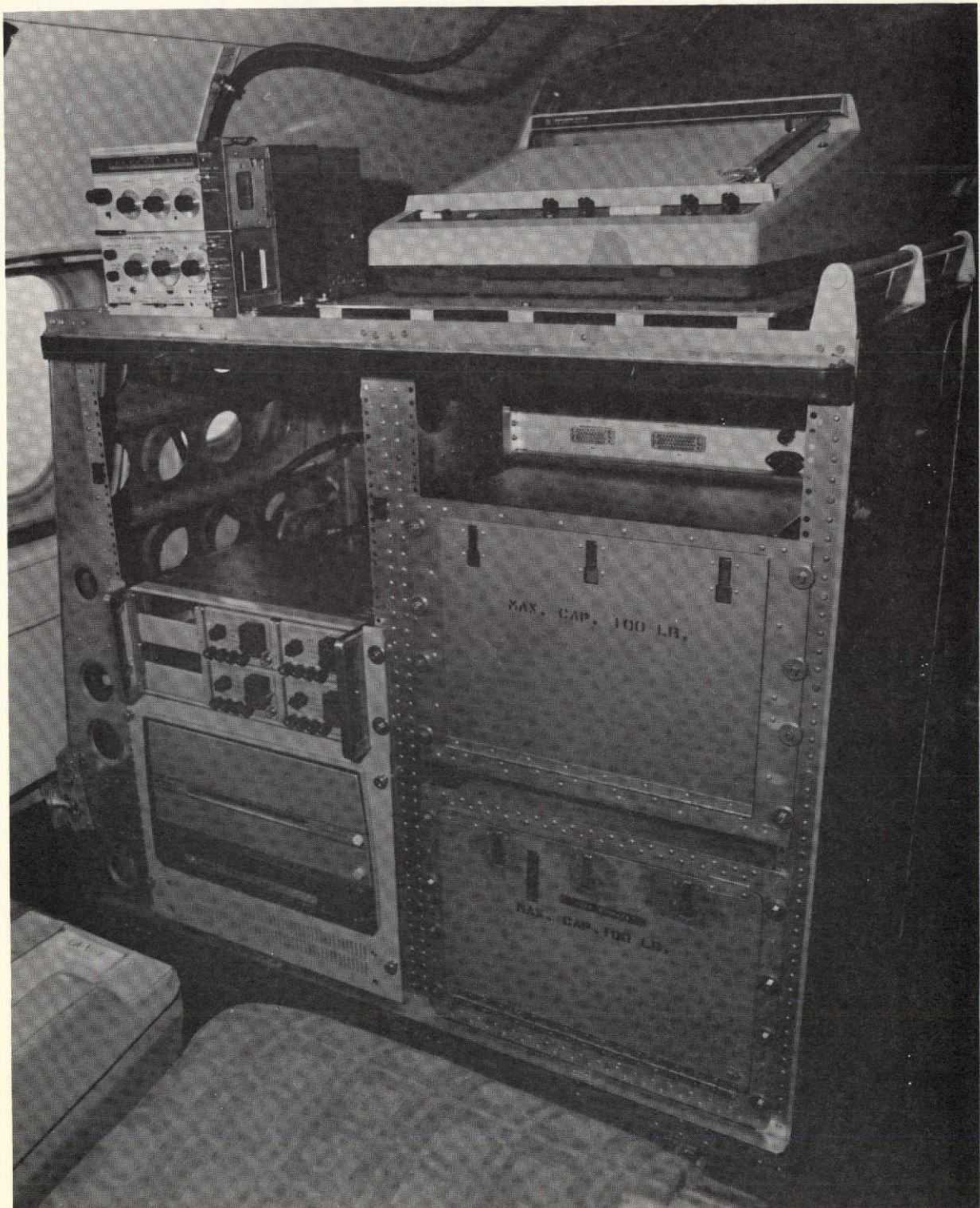


Figure 10.— Plotter, hard-copy unit, and voltage calibrators (ADDAS) in CV-990 aircraft.

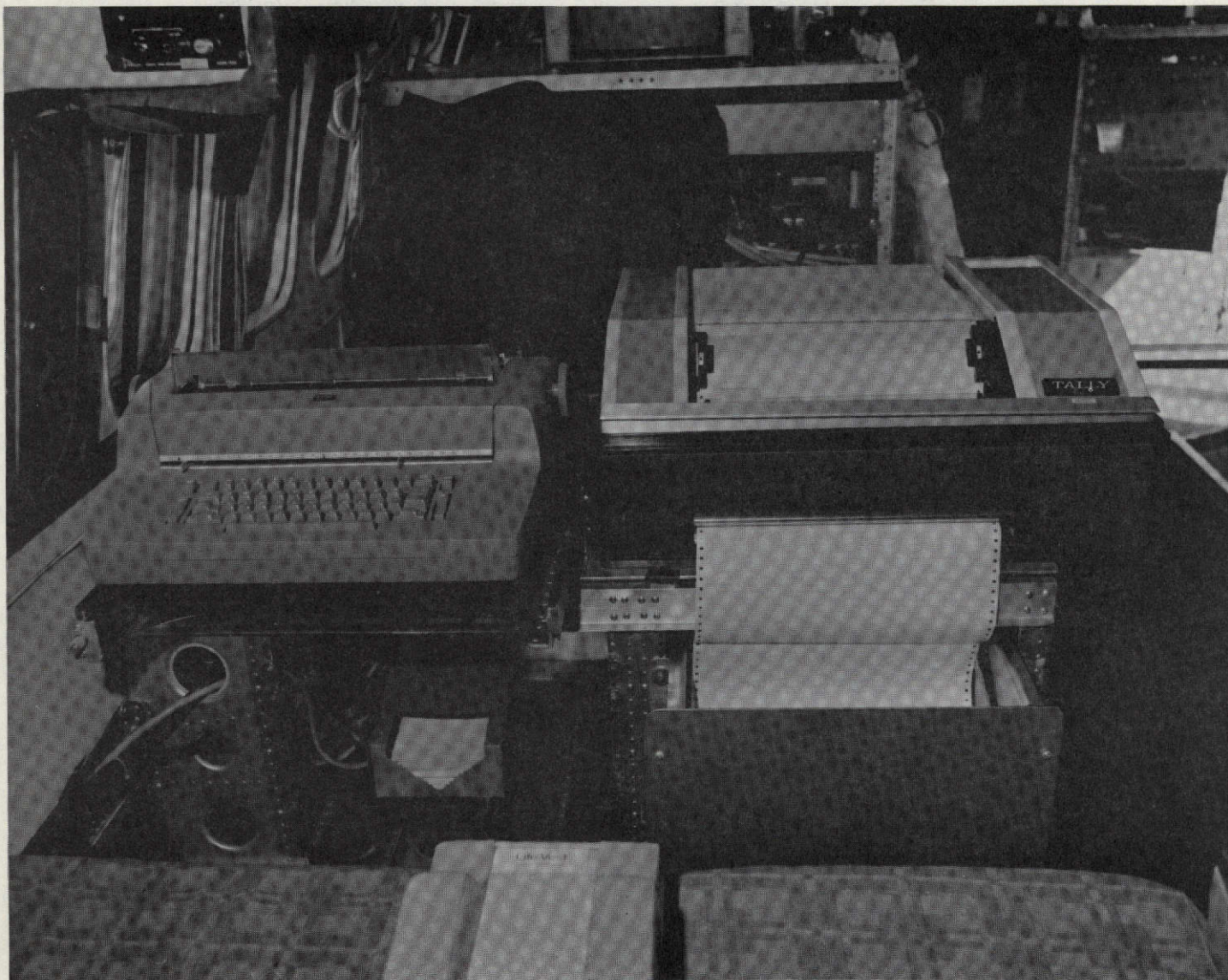


Figure 11.— Typewriter terminal and line printer (ADDAS) in CV-990 aircraft.

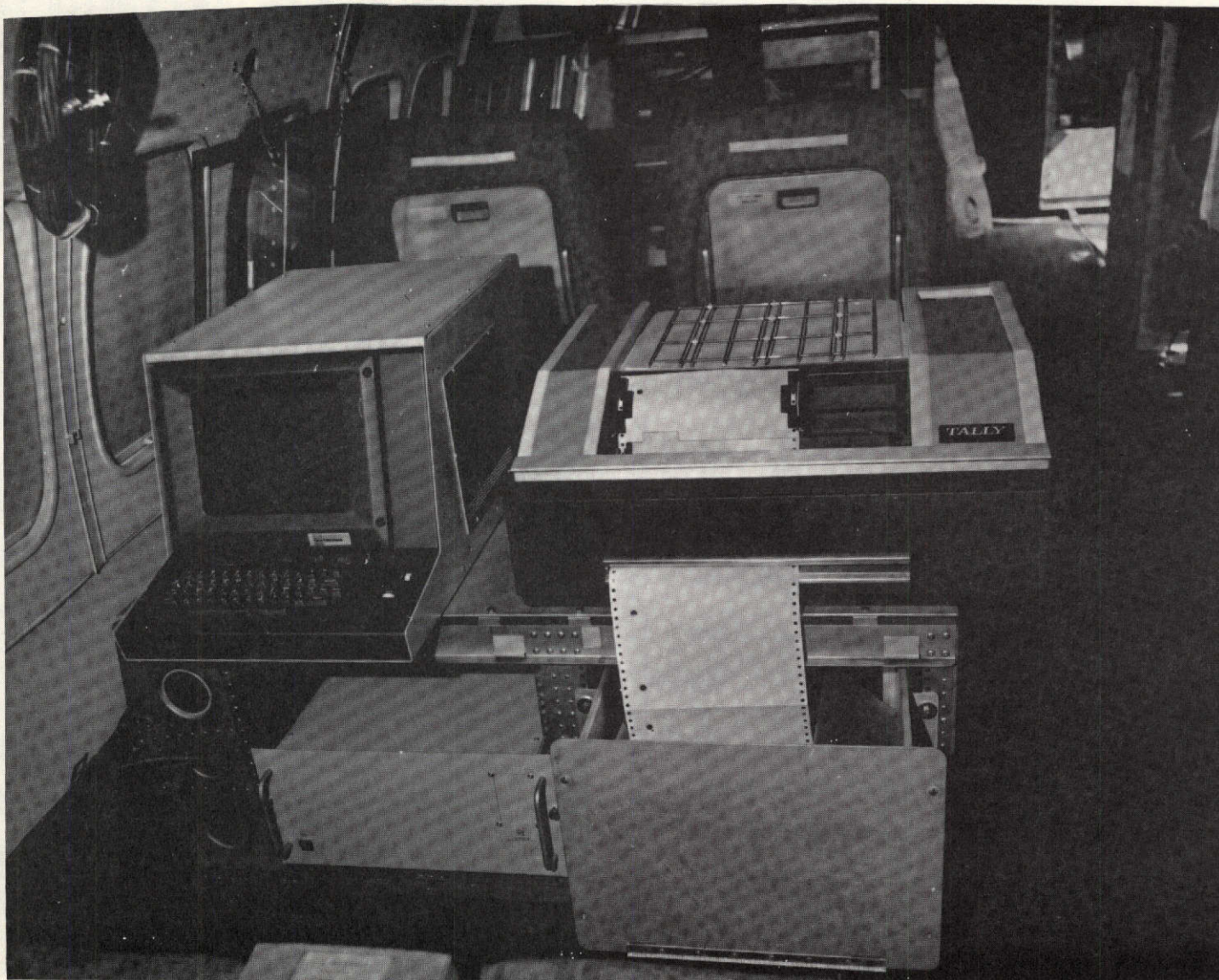


Figure 12.— Interactive terminal and printer (ADDAS) in CV-990 aircraft.

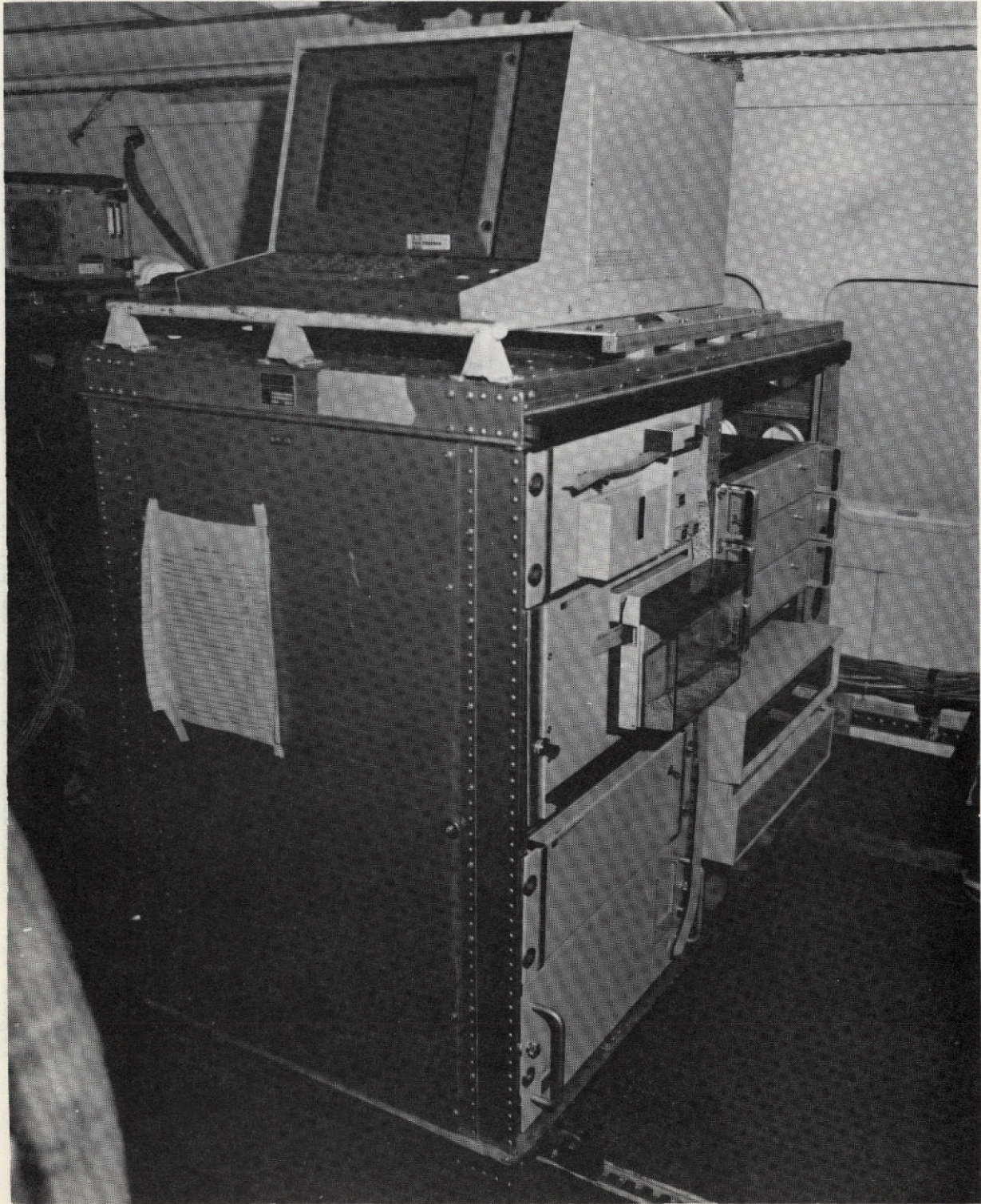


Figure 13.— Control terminal (above) and paper tape systems (ADDAS) in CV-990 aircraft.

information on the television monitors, the line printer, the plotter, and the interactive terminals. The software is parameter driven to allow variations suitable to the mission-specific requirements while still maintaining a highly reliable software set that has been debugged and proven beforehand. This allows a fairly short turnaround time between flights.

After initialization, the executive processor is capable of running a timeshared "Basic" language interpreter, in lieu of the real-time executive, to support experimenter interaction with a data base stored in the disc memory. This data base contains a comprehensive record of the most recent 10 min of data and a decimated record of approximately 1 percent of the data recorded throughout any single flight. The experimenter may perform any operation on his data, and the data from other cooperating experiments, if it can be supported by "Basic." Such operations as statistical comparisons, plotting the data of one experiment with that of another, filtering, and integration can be programmed and run on individual terminals simultaneously.

The executive processor can also develop, compile, and run Fortran programs, but not at the same time it is supporting timeshared "Basic." Neither timeshared "Basic" nor Fortran special routines interfere with the normal data system functions of the data processor, that are protected after initialization. The software operating systems are fairly flexible and capable of supporting the continuously changing requirements of the aircraft research environment without abandoning useful previous developments.

GROUND-BASED SIMULATOR

In support of both the ADAMS and the ADDAS airborne intelligent data systems, we have constructed a ground-based system of components that are compatible with, and in some cases identical to, their flight equivalents. This system is configured to support the functions of software development, experiment preprocessing, limited data postprocessing, and simulation.

The largest software development task is the development of systems and applications software of a general-purpose nature, applicable to the flight data systems no matter what the experiment configuration. However, there is a continuing need to support the special requirements of each new experiment as it is prepared for flight. Some, but not all, of this support can be accomplished in the aircraft systems, because of the incompatibility of merging the operational aspects of an ongoing mission with the special requirements of integrating software for new experiments and missions. The logistics and maintenance requirements of the aircraft make it difficult or impossible to predict the availability of services, and there are times when only the ground-based facility is available for use.

In the area of experiment preprocessing, this facility is used to translate experiment-specific software from source language into a code compatible with the aircraft operation. Data from punched paper tape, punched cards, digital magnetic tape, and disc cartridges are made available to the flight systems in a suitable form. In addition, the system is used to compute

support data and experiment calibrations before flight. Postflight processing is done to evaluate some data on a limited basis, and on occasion to translate data into other formats. This pre- and postflight processing is a relatively minor aspect of the use of the ground-based system, however, because other ground-based facilities of much greater capability are normally used by the investigators in the course of data reduction.

Simulation of the flight data systems is useful to prevent abortive attempts at installing equipment in the aircraft before it has been proven compatible and productive. The ground-based facility when used in this capacity forms a first step in the process of experiment integration. Then a successful experiment is integrated into flight hardware in an expeditious manner.

PART II

OPERATIONAL EXPERIENCE

DEDICATED FACILITY (C-141 ADAMS)

Integration and Checkout

Installation of ADAMS hardware was completed in late January 1974, and full-system debugging commenced using the standard utility and diagnostic software supplied as part of the total contract effort. By late March, hardware checkout and software integration was sufficiently complete that ADAMS could provide on-line experiment support. Meanwhile, in the January to March period, three experiments were flown on the aircraft to evaluate the performance of telescope optics, stabilization, and tracking systems.

The first experiment to use the ADAMS was a Fourier interferometer for planetary spectroscopy in the 1.5- to 6- μ range. In preparation for this experiment, a special-purpose software program was generated to process raw data into interferograms. Data from previous (ground-based) observations were supplied by the experimenter, who then compared the resulting interferogram with that from his own computer program. Agreement was good, and the experiment-specific software was verified.

The data system performed satisfactorily during three flights with this experiment in early April, but the local environment created by the telescope stabilization system (vibration and EMI) had a significant adverse impact on data quality. The next experiment, a Michelson interferometer for spectroscopy of far IR sources, had internal difficulties and did not achieve on-line operation with the data system on two flights.

The third experiment utilizing the ADAMS was a far IR photometer system for mapping the galactic center, and was conducted in a four-flight series in early June. In this case, data were acquired and stored, and no on-line processing was required. The data system operated as programmed and, once the pickup of vibration and EMI by the experiment from the telescope systems was resolved, several good-quality, high-resolution scans of W51 were obtained. These scans provided apparently unique data on this astronomical object in the far IR region.

This flight series brought to a close the initial operational shakedown of the entire facility. The ADAMS was shown to be performing its primary functions of accurate data acquisition and recording; on-line processing of experiment data was also demonstrated. Computer-controlled telescope tracking and scanning is now functioning on a routine basis; further software development is being done as the full system capability comes into use.

Preflight Simulation

When the telescope simulation laboratory is fully implemented, preflight verification of the experimenter's flight package will largely be done there, and final integration with aircraft systems will occur on the day of the first scheduled flight. The simulation laboratory will duplicate aircraft

mechanical and electrical interfaces, and will provide optical facilities for alignment and focusing on target sources, as well as data processing equipment that is functionally equivalent to the ADAMS. Present plans do not include simulation of flight environment parameters, such as pressure, vibration or EMI; these must be accounted for in the design and testing of the experiment prior to arrival at Ames, using values given in the C-141 Experimenters' Handbook (ref. 3) or by special arrangement with the ASO/AIRO facilities manager. (Experience to date has shown that vibration and EMI problems do exist but are amenable to solution.)

As noted, the simulation laboratory is presently fitted with ADAMS components for translation and verification of experiment-specific software. A typical user will relay his software plans and format to Ames about two months before a scheduled flight series, preferably as proven and debugged software modules written in Fortran or assembly language compatible with that used in the data management system, but if necessary in equation form for coding and integration by ASO support personnel. Integration times have varied from one week to one month, but should consistently approach the shorter period as aircraft utilization rises to full operational capacity.

The data system components assembled in the simulation laboratory are used for both ADAMS and ADDAS program development. In this capacity, the utilization factor of the laboratory is currently in excess of 50 percent of time available. This equipment is also a ready reserve to replace malfunctioning flight units.

Software-equipment data interactions in real time are not sufficiently documented to report at present. This area will be addressed in forthcoming publications.

Utilization and Support Manpower

Utilization of the C-141 data management system was relatively modest during the facility shakedown period from March to June 1974. Data from primary experiments were recorded and processed, and those from two secondary experiments were recorded as well. The secondary experiments were a water-vapor radiometer, and a far IR modular interferometer that measures the upper-atmosphere emission spectrum. Both were used as background diagnostic devices for the primary experiment, but also yielded scientific results of their own. They are being retained as semi-permanent installations. The interferometer experiment has, at present, a built-in computer that communicates with the ADAMS system for data and software, but processes the data separately from the ADAMS record. Final recordings of the processed data are made by ADAMS on magnetic tape.

Present software programs allot about 20 percent of the data processor capacity to recording functions and 40 percent to on-line processing of experiment data. The remainder, about 40 percent, is uncommitted. The executive processor is operating at about 60 percent of capacity when all present software is functioning.

Personnel to support both ADAMS and the CV-990 ADDAS operations are drawn from a common manpower pool for more effective response to fluctuating demand. All personnel (a total of four or five) have access to the simulation laboratory for software development, and dual training is the rule. On C-141 flights during the facility shakedown period, two ADAMS operators and two telescope operators participated in the training program, while primary experiment support consisted of the principal investigator and two associates. Now that routines are established, direct in-flight support of these three systems - the ADAMS, the telescope, and the primary experiment - requires three people, although some backup is desirable for the experimenter on flights of typically eight hours duration.

MULTIPURPOSE FACILITY (CV-990 ADDAS)

Integration and Checkout

Design studies for the ADDAS system were initiated in late September 1973 and had developed to the hardware procurement stage by January 1974. System logic and the functional roles of hardware and software were developed in accordance with the basic concepts of the ADAMS system, but with specific adaptations reflecting the multiexperiment mode of operation and the base of operational experience with the CV-990 precursor system.

Software development also began in September 1973, using the precursor package to indicate which format and data processing methods had proved suitable for past missions. About 3 man-years were required to complete the current operational software, including that for the first expedition, an international meteorological program, referred to as the GARP Atlantic Tropical Experiment (GATE), which is in progress.

Hardware integration and checkout began on June 1, 1974 with concurrent software verification in the simulation laboratory. Final onboard checkout of the primary recording functions was completed before the first engineering check flight on June 25. Minor modifications to secondary data management functions and software control were completed during the early flights of this initial ADDAS mission. A full functional operating capability has been achieved, although some software development continues during the day-to-day flight operations.

Preflight Simulation

The multiexperiment payloads characteristic of CV-990 missions are not amenable to full-scale preflight simulation in a ground-based facility. Present practice is to integrate experiment and support-systems software (as far as possible) in the simulation laboratory, usually without signal inputs from experiments. Final software verification takes place on the ADDAS in the aircraft during experiment installation. This approach follows the pattern developed for the precursor data system (as an interim measure), but tends to

shift the burden of experiment-specific programming from the experimenter to the ASO data system manager. In turn, the manager's knowledge of experiment data characteristics (at best second-hand) may delay the resolution of some software problems unnecessarily. As the full potential of the new ADDAS for on-line experiment support is realized, it will be necessary to accommodate a larger portion of the preflight simulation of both hardware and software in ground-based facilities prior to experiment integration into aircraft systems.

Utilization and Support Manpower

Initial installation and checkout of ADDAS hardware was accomplished in the five weeks just prior to the remote-based GATE mission. Experiment installation and onboard hardware/software verification took place in the last three weeks of this period, and two local checkout/data flights were made to complete the premission preparations. Since this was the first use of the ADDAS, support manpower and man-days of effort were far in excess of normal; upwards of eight people were involved at various stages, for an estimated 60 man-days of effort.

Eleven experiment systems and four aircraft support systems were on board for this mission, and all delivered input data to the ADDAS for recording. Raw data were processed for each experiment. Overall about 70 percent of data processor resources and 30 percent of the executive processor resources were utilized.

SYNTHESIS OF OPERATING PRINCIPLES AND INDICATED

FUTURE DEVELOPMENTS

Present developments indicate that the basic nature and capabilities of intelligent data systems are in a period of rapid evolution, caused in part by the availability of inexpensive minicomputers and peripheral equipment, and in part by new ways of thinking about data from the software point of view. To characterize this evolution, the more significant trends are extracted from our current design and operational experience, and used to extrapolate toward the systems of the future.

It appears that intelligent data systems are tending toward groupings in which the functions of intelligence are distributed, with interaction and mutual support for overall system reliability and effectiveness. Both the ADAMS and ADDAS systems have multiple, relatively autonomous computers. This suggests that future intelligent data systems may have more interconnected computers communicating with one another. This could come about through the microprocessors that are currently becoming available as large-scale, integrated, semiconductor elements. They find application now in portable calculators. In the future, however, they may be associated with experiments in which data streams that are now analog may become digital data buses, and one-way data flow may become bilateral digital communications. A fore taste

of this development has been proposed in recent data management concepts for the Shuttle Spacelab (ref. 2), with separate, dedicated microcomputers for experiment control and monitoring. The failure of a microprocessor or microcomputer would impact only the experiment to which it is attached while the rest of the system could survive intact.

We have also seen a marked increase in interaction between man and machine to the benefit of both. Artificial intelligence gives the technological capability of reducing or eliminating the repetitious tasks of data logging, calibration, and conversion of data to a form of display suited to human analysis. With this capability has come the problem of specifying in software how it is to be deployed for any given experimental situation. The systems discussed here have demonstrated that this problem can be reduced by permitting experimenters a range of options to be selected at will to accommodate changing situations. Human judgment and interaction can turn the basic routine of raw data acquisition into a viable, adaptive experience of information retrieval and evaluation. This suggests that the future intelligent data system will be characterized by a vital interaction between experimenter and hardware, with a larger amount of research information and less raw data. More processing will be done at or near the sensor and condensed data forms such as statistics images and spectra may augment or replace the present serial data streams. Interactive display devices will very likely become more convenient and personal, and perhaps be hand-held, personalized versions of the present keyboard CRT.

In software development, experience has shown a great reduction in fixed-purpose modules and an increase in parameter-driven adaptive modules, orchestrated by an executive program according to the needs of a particular mission. Continuing this trend, the future should see the writing of software of the greatest generality - program generators that will permit the rapid and reliable reprogramming of data systems to accommodate even large changes in the uses and characteristics of the available computer resources. This will also provide an immediate improvement in functional reliability, permitting failed components to be programmed out of critical uses, and redundant or spare components to be applied to higher priority tasks.

In the broadest view, our experience has shown an increase in the capacity of intelligent data systems to gather and process more information at less cost than was heretofore possible. If this trend continues, the challenge of the future will be to propose more useful experiments and make better application of the information obtained.

PART III

SHUTTLE SPACELAB APPLICATIONS

SHUTTLE SPACELAB APPLICATIONS

The evolution of research-oriented data management systems has been both accelerated and given new direction by the very rapid development of computer-related technology in the last few years. Design philosophies are changing and new logic patterns are being applied to produce flexible, adaptive systems that are increasingly interactive with other devices and with human operators.

Recent advances in airborne data handling systems illustrate these trends and point up design concepts that appear relevant to analogous Spacelab systems. In brief, we have seen that:

1. Distributing intelligence among several relatively autonomous computers enhances reliability with respect to the primary function, the acquisition and recording of precision scientific data. Alternate processors and subsystems can be programmed to assume primary roles in the event of component failure.
2. Software format is evolving in the direction of parameter-driven adaptive modules, coordinated by an executive program according to the specific needs of a particular mission. In this direction lie functional and programming reliability with ready accommodation to diverse demands on existing resources.
3. Experiment-dedicated microcomputers with interactive display devices will allow increased processing and interpretation of experiment data at the source, with condensed data forms rather than streams of raw data flowing into a central recording system.
4. Software requirements are reduced and the range of options is increased when human judgment and direct interaction with data systems operate in response to the changing situations or unexpected events that inevitably occur in the course of scientific research.

These innovative design trends serve to enhance rather than reduce the role of man in Spacelab research. Supported by an intelligent data system, the trained scientist can undertake tasks of greater magnitude and complexity than heretofore, and by effective use of interactive hardware and software, he can accomplish these tasks in less time and with greater precision.

REFERENCES

1. Mulholland, D. R.; Reller, J. O., Jr.; Neel, C. B.; and Haughney, L. C.: Study of Airborne Science Experiment Management Concepts for Application to Space Shuttle. Vol. II. NASA TM X-62,287, July 1973.
2. Operational Concepts for Selected Sortie Missions, Executive Summary. Contract Report NAS10-8395 prepared for NASA/KSC by TRW Systems Group of TRW, Inc., June 1974.
3. Investigators Handbook, C-141 Airborne Infrared Observatory. July 1974. (Available on request from the Airborne Science Office, Ames Research Center, NASA).